INSECTS:
A NUTRITIONAL ALTERNATIVE

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I. Introduction

The use of insects as human food seems either very odd or very awful to many people inhabiting so-called civilized nations. Nevertheless, insects have always been used as food by humans all over the world, particularly in tropical climates. The widespread use of insects as food has been documented by many world travelers and anthropologists. For unknown reasons, the use of insects as food is rare among the more industrialized Western cultures. Insects are commonly used as food by the hunting and gathering societies, and this will be described in detail in Section II.

Strong cultural conditioning forms people's food habits. In the United States, the suggestion of using insects in our diet is usually met with intense resistance. Although most insects are beneficial, they are viewed as dangerous pests, a threat to our food supply, dirty, and disgusting. This strong dislike can interfere with our ability to devise creative alternatives for solving food and nutritional problems on Earth as well as during space travel.

Long-term space travel involves a number of challenging nutritional problems, including providing an adequate nutrient balance with a minimum number of components, choosing foods with acceptable tastes and consistencies, and being able to recycle wastes. A major limitation on the life support system design is weight. Insects are one of the lightest sources of high quality animal protein available, they can be used in waste recycling, and many species are quite tasty even to Americans. Dr. Margaret Collins, a zoologist at Howard University in Washington, D.C., when asked about the use of insects as food in space, enthusiastically stated "I'd rather eat dried termites than dried beef on a spaceship!"

A number of space food production schemes are being investigated, using both conventional and nonconventional resources. Of the former, growing higher plants in special chambers is currently being studied (Miller, 1981). Of the latter, studies on edible blue-green algae and on synthetic carbohydrates are under way. The CELSS (Controlled Ecological Life Support System) program of NASA has not considered the use of insects in any form for space travel. Due to the complex problems of a CELSS, all possible alternatives should be explored.

Since most of the food produced in space may consist of plants, animal protein supplements may be needed. Besides adequate protein with the proper amino acid content, there is a basic need for variety in the American diet. A well-balanced diet is composed of a foundation diet providing the daily nutrient requirements and a supplemental diet for added food energy to meet caloric needs. An example of a typical balanced diet (Modell, 1977) for an American adult is shown in Table I below.

TABLE I

Balanced American Diet

Foundation Diet (1250 calories)	Supplemental Diet (1150 calories)
100 g. meat	100 g. meat
285 g. fruits	150 g. fruits
70 g. bread	23 g. bread
300 g. vegetables	24 g. sugar
488 g. milk	21 g. butter
50 g. eggs	14 g. mayonnaise
30 g. cereal	28 g. oatmeal cookies
1323 g.	100 g. pudding
	170 g. soft drinks
	360 g. tea or coffee
	990 g.

The total number of calories in these two diets is 2400, including a total protein content of 96 grams. The number of different types of foods available on a long-term space mission will be extremely limited. The psychological and physiological effects of such restricted diets for long periods need to be investigated in healthy humans.

Most of the data available on the effects of extremely restricted diets are from critically ill patients with various barriers to normal food intake. These barriers include surgical removal, diseases, or congenital malformations of the alimentary tract. These nutritional problems are treated by giving the patients chemically defined liquid diets either orally or intravenously. A comparison of the commonly used chemical diets for oral intake has been done by Young et al. (1975). Chemical diets have been evaluated to some extent for possible use in space travel by Winitz et al. (1965). A chemical diet, containing amino acids, vitamins, minerals, salts, glucose, and ethyl linoleate as the source of essential fat, was given ad lib. to 24 healthy male volunteers for 19 weeks. Only 15 of the subjects remained in the study for the full 19 weeks (the reasons for the loss of 9 subjects were nonmedical but unspecified). No adverse physical or psychological effects were observed in these 15 individuals.

The use of intravenous feeding alone (total parenteral nutrition or TPN) has been used since the late 1960's. The technique has prolonged life for patients who can never again return to oral food intake. One of the first patients able to continue TPN at home and live a normal life was reported by Jeejeebhoy et al. (1973). The 36-year-old woman began TPN in 1970, and the review by Shenkin and Wretlind (1979) stated that she had no serious problems after over 8 years on TPN. Not all patients are able to make a successful adjustment to such extreme nutritional therapies, and a number of psychological problems have been reported in patients on TPN (Malcolm et al., 1980). There are also physiological and morphological changes in the intestines of long-term TPN patients. The diets that are eventually used in long-term space travel may have to be as different as some of the diets used on Earth for medical reasons.

The use of insects in the human diet seems no stranger than some of the chemically defined diets currently in use.

Although the regular use of insects as human food has mainly been avoided by industrialized societies, there has been some interest in the subject. Due to projected population increases and food shortages in certain areas of the world by the 21st Century, scientific interest in alternative food sources has increased. Because of the significant role of insects as a protein source in the diets of a number of primitive peoples, research on the nutritional potential of insects is being conducted in Africa, the United States, and Mexico. An article on these studies at the National Autonomous University of Mexico (Eerde, 1980/1981) is what originally prompted this review. These and other nutritional studies are discussed in Section V.

The idea of insects being used to help combat hunger in the world is not new. A charming 19th Century book called <u>Why Not Eat Insects?</u> (Holt, 1885) suggests this as a partial solution to feeding the poor, but the author was very much in favor of including insects in everyone's diet. It is argued that many insects are strict vegetarians and should be much less objectionable as food than scavengers considered to be delicacies, such as crabs and lobsters. It is certainly a valid point that on close inspection the diets of many shellfish would make them less appetizing than insects. The point is also made that since many people eat snails, oysters, and bird's-nest soup just because it is fashionable, it would be equally possible to influence people that it is stylish to eat insects. As

Holt states, "Why does not some one in a high place set the common-sense fashion of adding insect dishes to our tables? The flock would not be long in following" (Holt, 1885, pp. 29-30). We are also reminded that, in The Bible, Moses specifically states that locusts and beetles may be eaten (Leviticus 11:20-23).

Besides Holt's information, a number of other individuals have compiled data on insect-eating or entomophagy. Much of the information is anecdotal from world travelers and anthropologists. Some extensive reviews of the subject have been published by entomologists, zoologists, and nutritionists who had a personal interest in the subject. Since some of these reviews (e.g., Bodenheimer, 1951; Taylor, 1975) may not be readily available, selected citations from their extensive bibliographies are listed in a separate section at the end of this report. The present review includes highlights of the most interesting older information and more current information from 1976 to the present.

Class Insecta under Phylum Arthropoda contains more species than the entire rest of the animal kingdom. Insects are about 4/5 of all animals (Mamley, 1976). Although only about 800,000 species of insects have been described, there are estimated to be over a million, possibly two million (Hickman, 1967). The largest group of insects are the beetles, which are about 40% of all insects (Taylor, 1975). The larval stages of many beetles are consumed by humans. Most insects are beneficial, by serving as food for other animals, by preying on harmful species, and by pollinating plants. Many of the plants humans use for food require insect pollination. Caron (1978) estimates that honeybees are responsible for about 90% of planned pollination and that about 1/3 of the plants in the American diet (including crops fed to livestock) must have insect pollination for reproduction.

Before we can expect people to overcome their prejudices against insects and start eating them, some innovative marketing techniques will be needed. A great deal of this involves desensitization so that more neutral or positive attitudes towards insects in general can be produced. A recent effort in this regard was a lecture on "Cooking with Insects" at the Insect Zoo in the Smithsonian's Museum of Natural History in Washington, D.C. The 5-year-old Insect Zoo has live insects and gives people a chance for a "hands on" experience with them. The museum provided freshly baked chocolate chip cookies, made from flour containing ground up mealworms (the larval stage of a grain beetle). Most of the over 100 people attending the noontime lecture were children, and they gobbled up the cookies without hesitation. The parents were slightly less enthusiastic, but many of them were able to take a bite or two.

The main intent of this report is to generate more serious interest in the potential uses of insects in the nutrition of humans and domestic animals, as well as in the recycling of wastes. With the possibility of scarcer resources in the future, it may be in our best interest to find ways of utilizing insects.

II. Types of Insects Consumed

Insects have always been eaten by certain groups of humans. Many of the people who eat insects today are in the developing nations. Examples of insects in the human diet can be found on nearly every continent. Entomophagy used to be even more common among native cultures. The influence of Western culture has given some of the people in developing countries the notion that it is more "civilized" to avoid eating insects, although this may be changing (Meyer-Rochow, 1976). Insects become part of the human diet for several reasons: 1) accidental ingestion by contamination of other foods; 2) as a gourmet or novelty item; 3) as a medicinal agent; 4) as a normal dietary constituent; 5) as a last resort for survival. The main emphasis of this review is on insects as ordinary human food, although the other reasons for ingesting insects are mentioned. A table summarizing some of the insects eaten in various countries is included at the end of this section.

Although few Americans or Europeans eat insects by choice, significant amounts of whole insects and insect parts are consumed due to "contamination" of our food. This is because it is impossible to remove all insects or insect fragments from foods such as dry vegetables, grain products, spices, and fresh produce (Caron, 1978). The United States Food and Drug Administration (FDA) sets standards for the amounts of insect parts allowable in certain foods. For example, some of the 1971 limits for insect-infested or insect-damaged portions are as follows: 10% by count in dried prunes; 50 insect fragments per 100 grams peanut butter; 1% by weight in wheat or whole black pepper; a maximum of 10 fruit fly eggs or 2 larvae per 100 grams tomato juice (Taylor, 1975).

Besides contamination of our food by insects, we also indirectly consume insects by eating animals (fish, poultry, and even pigs) who eat insects (Taylor, 1975). Another indirect route for insect consumption is our significant usage of the insect product, honey. Bees drink the nectar of flowers, which they then concentrate and regurgitate as honey into the honeycomb. This substance, which is actually bee vomit, is used as a sweetener in all kinds of recipes in Western society without regard to its actual origin. Honey is a major part of the diet in certain primitive African tribes (Bodenheimer, 1951) and has often been taken medicinally as a laxative, as an astringent, as a flavoring for medicines, and for many other purposes in folk medicine.

Insects have been commonly used in folk remedies all over the world, not just by primitive tribes. Certain insects contain substances that exert various pharmacological effects. For example, several species of blister beetles (Lytta vesicatoria and Mylabris species) contain Cantharidin, Spanish fly, the ingestion of which may cause irritation of the urogenital and gastrointestinal tracts as well as kidney failure in large doses. The substance also causes skin blisters when topically applied. In small quantities, this substance is used in preparations that are supposed to induce hair growth. Cantharidin has some legitimate applications in human and veterinary medicine (Taylor, 1975).

The ingestion of insects to prevent starvation has been reported throughout history. Although insects have been eaten for survival, such as in concentration camps during World War II, the use of insects in wilderness situations is rarely discussed in contemporary survival manuals. Taylor (1975) found only two such books in the United States. One is published by the Navy (the Survival Department of the Fleet Aviation Specialized Operational Training Group Pacific

Fleet) and is not available to the public. It consists of a set of instructions for survival in Southeast Asia, of which very few deal with insects as food. The other survival manual which mentions edible insects is the Desert Survival Manual of the Joint Maricopa County Department of Civil Defense and Emergency Services in Phoenix, Arizona. Boiled or fried grubs (found in rotten wood or in the ground), hairless caterpillars (some hairy types are poisonous), and the lubber grasshopper (cooked) are three recommended insects.

Other than survival, the only acceptable way insects become part of the human diet in the United States and most of Europe today is as a gourmet item. Most of us have heard of fried grasshoppers and chocolate covered ants, and such exotic foods are often regarded as a joke. Nevertheless, these edible insects are available in super-markets, and the author once tried one of them on a dare. As food, insects may seem odd to us; however, people in many other countries consider insects to be just like any other food.

Insects are more frequently eaten in tropical areas where they are of a larger size and more numerous (Taylor, 1975). Although nearly all families of insects are consumed somewhere in the world, the most commonly eaten are grasshoppers and their migratory phase -- locusts (Caron, 1978), followed by termites (DeFoliart, 1975). Insects that are not usually eaten are the aposematic (conspicuously colored) varieties which may have either a bad taste or toxic components (Gamble, 1976). This warning coloration is a common means of defense in the animal kingdom, and predatory animals often will avoid eating certain brightly colored animals. Humans probably learned which insects are good to eat by observing the food choices of lower animals. Most of our knowledge today of edible insects comes from traditional folk wisdom and not from scientific investigation.

Although insects are eaten all over the world, reviews on entomophagy usually mention the food habits of the following groups as being of special interest: 1) the Australian aborigines; 2) North, Central, and South American Indians; 3) the rural Thais and Laotians of Southeast Asia; 4) a number of African tribal cultures. Entomophagy is associated with so-called hunting and gathering peoples. Since many of the accounts of insect-eating originate with anthropologists and world travelers, not entomologists, the exact species are often unknown. For example, the Australian desert aborigines eat a yellow and green caterpillar called the witjuti or wichetty (wichety, witchity, witchedy, etc.) grub, which has never been identified. An educated guess has been that the insect is the larva of a common giant moth, possibly some Cossus species (Taylor, 1975). The wichetty grub and many other insects used as food (honey ants, beetle grubs, cicadas, and leafhoppers) are chosen as totem animals having complex religious rituals associated with them. The other frequently discussed insect eaten by aborigines is the Bugong moth (Euxoa infusa), a dark brown Noctuid moth which swarms in large numbers from November through January. When first consumed, violent vomiting results, which subsides in a few days after some sort of tolerance is acquired (Bodenheimer, 1951). Due to the influence of civilization on the aborigines, their insect-eating has apparently decreased. Many of the original extensive reports of the insects eaten in Australia were from around the turn of the century. More recent reports indicate that the Walbri and Pintupi tribes of Central Australia still eat a great number of insects (Meyer-Rochow, 1976).

The Indians inhabiting the Americas have eaten a variety of insects. Those cultures which have been least affected by modern industrial civilization and have remained hunting and gathering societies still rely on insects as significant protein sources. These Indian groups include tribes around the Amazon (the Yanomamo, Iquito, Mave, Cayapa, etc.) and other remote areas. Insects eaten include different types of ants, caterpillars, beetle grubs, wasps, and stingless bees, and their honey. The significance of insects as protein sources in Indian diets has been underestimated by some anthropologists, resulting in the mistaken notion that the diets were unusually low in protein (Posey, 1978). Bodenheimer (1951, p. 5) makes the following statement in the preface to his monumental review of insects in the diet of humans:

> "In the tropics the insects often fill gaps in the one-sided vegetarian diets of food gatherers, and they even do so in regions of highly developed monsoon agriculture. This in fact is the key to the true interpretation of the puzzling results obtained by a number of physiologists who have studied the diets of tropical races and found them to be deficient in animal proteins and fats, and yet the people were fit and obviously adequately fed. The constant eating of termites, caterpillars, locusts, etc. in substantial quantities was not taken into account."

The Indians of the United States, particularly the tribes west of the Mississippi, ate ants, bees, caterpillars, cicadas, maggots, body lice, flies, and many species of grasshoppers. The grasshoppers periodically swarmed in such numbers that the European settlers thought of them as plagues. One source of animosity between the Paiute Indians and the white settlers was the Mormons' efforts to kill these grasshoppers in Utah in the late 1800's. Ironically, the Mormons had to eat grasshoppers occasionally, after the insects had eaten all their crops! The Paiutes and some other tribes may still eat insects today, although the available literature is ambiguous (Bodenheimer, 1951; Caron, 1978; Taylor, 1975).

Insects are definitely still eaten in many parts of Mexico. Researchers at the Department of Zoology of the Biological Institute at the National Autonomous University of Mexico have been studying edible insects and have cataloged at least 57 varieties actually used as human food. These include gourmet items, such as the maguey worms placed in bottles of tequila. This custom is old and dates back to the Aztecs, who believed a live insect in an alcoholic beverage imparted some spiritual significance to it (Taylor, 1975). Other insects eaten include various aquatic species, wasps, dragonflies, mosquitoes, caterpillars, ants, ant eggs, grasshoppers, and bees, to name a few. In Mexico City, where some gourmet restaurants serve insects, the market prices are high -- $9 per half pound of ant eggs for example (Eerde, 1980/1981; Mamley, 1976).

On the other side of the world, insects are eaten in many parts of Asia, from Indonesia to China, Laos, and Thailand. The peoples of Indonesia, which includes the islands of Sumatra, Java, Borneo, and others, eat grasshoppers, cockchafers, waterbugs, termites, crickets, dragonflies, lice, caterpillars, and beetle grubs such as palm weevils (Bodenheimer, 1951). A widely cited source of observations on the insects eaten in Southeast Asia is Bristowe (1953), an Englishman who visited Siam in the 1930's. At that time, the main insect eaters were the rural peasants as well as some members of the royal family of Siam. Bristowe's inquiries into their food habits revealed some embarrassment by the peasants about eating insects. Bristowe tried many of the insect dishes and liked them; he reported that the giant water bugs had the strongest taste. Other insects in the Laotian diet include dung beetles, cockroach eggs, cicadas, wasp larvae, ants, and termites. Information on insects eaten in China was provided by Hoffman (1947) while he was teaching at Lingnan University in Canton. Insects are often used medicinally in China. Those that are primarily consumed as food include silkworm (*Bombyx mori* L.) pupae, giant waterbugs (*Lethocerus indicus*), green bottle fly (*Chrysomyia megacephala* (F.)) larvae, cockroaches (*Periplaneta americana* and *P. australasiae*) served candied and otherwise, and locusts (Bodenheimer, 1951).

Africa appears to be where the greatest variety of insects are consumed by more groups of people today. The use of modern agricultural practices with pesticides has inhibited the consumption of insects in certain areas, such as the use of locusts by the African Bushmen (Taylor, 1975). Taylor lists a few of the insects eaten in Africa:

> termites and ants (Zimbabwe, Malawi, the Congo area, South Africa, etc.)
>
> dragonflies (Nigeria)
>
> grasshoppers, stinkbugs, caterpillars (the Bantu tribe in South Africa)

goliath beetle larvae and other grubs (Zimbabwe, South Africa)

locusts (Morocco, Algeria, Zimbabwe, Uganda, Malawi, Tanzania, etc.)

mole crickets (Uganda)

lice (the Hottentots in South Africa, the Pangine of the Cameroons)

Detailed and very interesting accounts of the insect-eating habits of various African tribes have been compiled by Bodenheimer (1951) and others. As previously mentioned, Western civilization has influenced some of these people to stop eating insects. However, there is recent evidence that great numbers of insects are still being consumed in Africa. This evidence involves scientific inquiry into the types of insects consumed and their nutritional values. Malaisse and Parent (1980) published a review of the more than 35 species of caterpillars consumed in Zaire. The study was performed for a doctoral dissertation at the National University of Zaire, and it includes complete descriptions of the ecology of the caterpillars, photographs, and nutrient analyses. Caterpillars are one of the most important types of insects consumed there, because of their numbers and their diversity. Another paper (Oliveira et al., 1976) examines the nutritional values of four of the insects eaten in Angola: the palm weevil larva (Rhynchophorus phoenicis F.), two types of caterpillars (Imbrasia ertli and Usta terpsichore), and a termite (Macrotermes subhyalinus). The nutritional content of these and other insects is discussed in Section V.

As shown in Table II, insects have also been consumed in Europe. The upper classes of ancient Greece and Rome considered the cicada and a beetle grub that feeds on oak trees to be true delicacies, according to Aristotle and Pliny. The exact species consumed have never been identified. The oak grubs were actually raised as food by the Romans, using flour and wine to fatten the larvae. These food habits did not survive to modern times (Holt, 1885; Bodenheimer, 1951).

The instances where insects are still used as human food by Westerners are discussed by Bodenheimer (1951, p. 6) under the heading "RELICS OF ENTOMOPHAGY IN EUROPE." One example is that ant pupae are used to flavor gin in Sweden. Children in southern France have been observed to eat grasshoppers, and certain beetles (Melolontha aprilina Duft) have been eaten in Italy. No information was located on current insect-eating in Europe, and it appears that there are very few places on that continent where insects are regularly part of the human diet.

People who eat insects are thought to have eccentric tastes by Western standards. Some of the most delightful anecdotes are accounts of the experiences of various American or European travelers who have been induced to try insect dishes in faraway places (Holt, 1885; Bodenheimer, 1951; Taylor, 1975).

TABLE II

ENTOMOPHAGY AROUND THE WORLD

Location	People	Examples of Insects Consumed	Ref. #
Arctic	Eskimos	maggots	25
N. and S. America:			
U.S.	Plains Indians	grasshoppers, head and body lice	6
	European settlers	grasshoppers (only in times of famine)	6
	Americans	accidental consumption; novelty dishes (fried grasshoppers)	-
Central & S. America	various Indians	flour made from maggots	26
Lowland Latin America (Amazon)	various tribes (Campa, Iquito, Mave, Yanomamo, etc.)	ants, beetle grubs, caterpillars	33
Mexico	not specified	57 varieties (grasshoppers, beetles, ant eggs, ants, locusts, wasps, flies, mosquitoes, lice, dragonflies, butterflies)	11
Mexico	Indians in Morelos	stinkbugs	17
West Indies	Indians; French colonists	palmworms	3
Asia:			
China	Cantonese	adult beetles, silkworm pupae, green bottle fly larvae, giant waterbugs, stinkbugs	17
India	Assamese	stinkbugs	17
Thailand	Thais (rural)	caterpillars, giant water bugs, locusts, termites, cicadas, bees, ants, beetle and wasp larvae	4
Laos	Laotians (rural)	same as those eaten in Thailand	4
Australia	Aborigines	witchity (witchetty) grubs, cockroaches, grasshoppers, butterflies, termites, cicadas, Bugong moth	3, 6, 20
Africa:			
Zaire	not specified	caterpillars (35+ species)	23
Belgian Congo	not specified	termites	38
Angola	not specified	Lake flies, caterpillars, locusts, termites, weevil larvae	31
Algeria, Morocco	Arabs	locusts	18
Europe:			
Rome	ancient Romans	beetle grubs	18
Greece	ancient Greeks	cicadas	18
S. France	children	grasshoppers	3
Sweden	not specified	ant pupae used to flavor gin	3
Italy	not specified	beetles	3
W. Germany	children in Lower Saxony	honeybees	37

III. Hazards of Insect Ingestion

Published reports on the adverse effects of eating whole insects or insect fragments are mainly anecdotal; however, some more technical articles, including clinical case histories and experimental studies, are available. Since there are estimated to be over a million species of insects, it would be surprising if all were completely safe to eat. The potential hazards of eating insects include mechanical damage (by sharp appendages), toxic components, allergy, infectious organisms and parasites carried by insects, nutritional degradation of insect-infested foods, and pesticide contamination.

Gamble (1976) states that there are very few reports of adverse effects of entomophagy. Gastrointestinal problems of varying degrees have occurred due to consumption of the Bugong moth in Australia, a paste made from termites in the East Indies, and after eating large quantities of whole termites in Africa (acute diarrhea resulted). An interesting aspect of the reactions to the Bugong moth by the aborigines is that although vomiting occurs when the moth is first eaten, the symptoms decrease with subsequent ingestion (Taylor, 1975) for unknown reasons. Intestinal impaction due to the chitinous skeletons of locusts have occurred in humans and monkeys due to ingestion of excess amounts. Individual sensitivities to certain caterpillars (*Anaphe* species) in Africa have resulted in 2 or 3 days of illness.

Some insects contain poisonous parts, which must be removed before eating. Gamble (1976) described some anecdotal reports of the head of a Maquara grub having intoxicating effects in Indians of Central America. European visitors were able to consume the bodies with no ill effects. In the Orient, two small red glands (believed to cause paralysis and death) are removed before eating a large water beetle. Feeding these glands to monkeys produced no adverse reactions, however. People in the East Indies avoid certain species of Orthoptera (includes grasshoppers and crickets) that are thought to be poisonous. The Japanese do not eat pupae living in the ground except wasps, since some may be poisonous.

Gorham (1976), who has worked for the United States Food and Drug Administration, summarized various considerations regarding the use of insects as human food. He concluded that because the potential health problems of entomophagy have not been thoroughly studied, it would be unwise to discontinue our efforts to reduce insect contamination of human food. A more recent and extensive paper by Gorham (1979) reviews the potential adverse effects of insects in food, including toxicity, allergy, dissemination of pathogens, and nutritional losses. The Federal Food, Drug, and Cosmetic Act (FD&C Act) defines insects in food as contamination and filth and sets guidelines for maximum amounts. However, Gorham states that certain foods of insect origin could be safe enough to supplement human diets and still be compatible under the FD&C Act. His main point is that one should not assume that all insect fragments in food are harmless.

Another health problem associated with such insect contamination of human food is that insects can serve as ingestant allergens. This may be the actual basis for certain food allergies. The potential allergic properties of seven common insect pests were investigated in 230 people with existing allergies and in 194 persons with no known allergies. These people were all given skin tests with extracts of the lesser grain borer (Rhyzopertha dominica F.), the Saw-toothed grain beetle (Oryzaephilus surinamensis), the Indian meal moth (Plodia interpunctella), the red flour beetle (Tribolium castaneum), the confused flour beetle (Tribolium confusum), the fruit fly (Drosophila melanogaster), and the rice or black weevil (Sitophilus oryzae L.). About 25% of the nonallergic and 30% of the allergic individuals had positive skin reactions to the insect extracts. The Indian meal moth extract was most frequently responsible for the skin reactions, followed by the red flour beetle. The lesser grain borer produced skin reactions less than the other insects tested. The insect extracts were also able to produce skin reactions after being boiled (Bernton and Brown, 1967).

Other routes for insects to cause allergic reactions are the well-known injection of bee venom and the inhalation of insect debris. Living insects become part of the air we breathe as a result of both migratory behavior and involuntary dispersal by various types of air currents and winds. Dead insects and insect debris also become part of dust, which can accumulate to a great extent in sheltered areas such as houses. Although the exact amount of insect debris in household dust is difficult to measure, insect remains are probably significant components. The allergenic substances in insects such as chitin, chitosan, and arthropodin are thought to be in the cuticle or exoskeleton; however, more research is needed to identify the specific chemicals. The allergic symptoms reported from the inhalation of insects are similar to those of hay fever and asthma (Perlman, 1958). Cockroaches have been known to cause allergies through both inhalation and ingestion, especially in overcrowded, infested areas (Choovivathanavanich et al., 1970). The allergic potential of insects should be considered when insects are introduced into human diets.

Insects can also act as hosts for various parasites that may be transmitted to humans. One example is a beetle (Palembus dermestoides) that carries the tapeworm (Hymenolepis dimunata). This insect is eaten alive in Malaysia as a cure for several diseases (including indigestion, asthma, low back pain, coughs) and as an aphrodisiac. Although reports of human tapeworms resulting from such "treatments" were not stated, the potential public health problem has been discussed by Chu et al. (1977). The authors indicated that tapeworm infections would be avoided if the insects were cooked before ingestion. Tapeworms are known to use grain-eating beetles as intermediate hosts (Gorham, 1979), so the potential health hazard is not restricted to Malaysia.

In addition to tapeworms, insects can carry pathogenic microorganisms, such as viruses, bacteria, fungi, and protozoans. Organisms causing polio, salmonella infections, and amoebic dysentery have been found in cockroaches (Gorham, 1976), and cockroaches and flies have been the sources of disease outbreaks.

Pathogens have also been found in or on grain-eating insects, flies, ants, and beetles. Home cooking usually kills these pathogens; however, contamination can occur during food processing (Gorham, 1979).

Microorganisms can be removed from live insects, even when intimately associated with their insect hosts. Brooks and Richards (1955) reported a method for removing intracellular symbiotes called bacteroids (because they look bacteria-like) from the German cockroach (Blatella germanica) using combinations of heat and antibiotics. Various decontamination procedures could be devised for certain insects in the human diet to avoid the transmission of disease.

Although cases of poisoning in humans after insect ingestion are rare, two such reports are presented, both in children. The first case was a fatal poisoning in a 4-year-old African child after she ate a grasshopper (Phymateus leprosus F.). This grasshopper is not normally eaten by the adult Swazis, since they know it is poisonous. Toxic symptoms of the heart and respiratory system were also produced in rabbits by feeding them this insect. It was not determined whether the poison originated in the grasshopper's metabolism or from a toxic plant that the insect ate. This species of grasshopper does have poisonous plants (wild cotton and Ceylon rose) in its diet (Steyn, 1962). Since many insects are herbivorous, this would have to be considered upon introducing new insects into human diets. The other poisoning case involves the blister beetle (Epicauta fabricii), commonly found in the United States. After swallowing one of these beetles, a 10-month-old girl vomited up the whole insect and then developed toxic symptoms including bloody urine, frequent urination, elevated white blood cell count, and elevated blood urea nitrogen. The child recovered after an 11-day hospital stay. The well-known poison in this insect is cantharidin, also a component of Spanish fly, which is prepared from powdered, dried beetles (Wertelecki et al., 1967).

Other substances identified in insects have tumorigenic properties. Mullins and Cochran (1973) found tryptophan metabolites, including xanthurenic acid and 8-hydroxyquinaldic acid, in American cockroach (_Periplaneta americana_ L.) excreta. These quinolines may contribute to tumors in the cockroach intestine. A common flour beetle, _Tribolium castaneum_, secretes a mixture of quinones which may be carcinogenic. When a similar mixture of synthetic quinones in either a water or an arachis oil vehicle was administered to mice, 15 out of 58 animals developed sweat gland carcinomas. Only one out of 15 mice in the control groups (given the vehicles alone) developed this tumor (Ladisch et al., 1968). It is not known if this represents a hazard to humans.

The effects of the ingestion of flour beetles were studied by Mills and Pepper (1939) using four human volunteers. Before testing the beetles in humans, a feeding study was performed using rats. Nine young rats were fed diets containing one percent crushed adult confused flour beetles (_Tribolium confusum_ Duv.) for 5 days, and 6 rats were fed diets containing one percent beetle larvae. No adverse effects were found on rat weight gain or digestion. The human subjects (age range 28 to 44 years) each ate 2 ounces of oatmeal infested with 25 adult beetles, 25 larvae, some pupae, skins, eggs, and excreta. No adverse effects on blood and urine analyses or bowel habits were found in the next 2 days. The investigators concluded that accidental ingestion of a few flour beetles in cooked cereals would not be harmful to humans.

Although occasional ingestion of insect-infested foods may not be harmful, some harmful effects have been found in albino rats fed steady diets of contaminated food. Significant increases in the occurrence of fatty livers (compared to rats fed uninfested grains) were found in 16 rats given diets containing jowar with 25% damaged kernels infested with Sitophilus oryza L. and Bengal gram infested with Bruchus chinensis L. for 8 weeks (Venkat Rao et al., 1960). A similar study was conducted by Rajan et al. (1976), in which 20 albino rats were fed diets containing infested maize and cowpea in a composition similar to that consumed by low-income groups in India; a control group was fed an uninfested diet. The infestation reduced the thiamine content of the grain considerably. Significantly reduced weight gain (calculated per 100 grams food intake) was found in rats fed the infested grains during the 4-week study. These rats also had a much lower food intake and more severe fatty livers than the control rats, as in the earlier study. The adverse effects in these two studies may be related to reductions in nutrient and caloric values by insect infestation (Gorham, 1979).

A final potential hazard of eating insects is pesticide contamination. Most of the people in the world who eat insects simply gather them in the wild. If more people in the industrialized societies were to collect insects for food, then care would have to be taken to avoid fields or forests contaminated with pesticides (Taylor, 1975). This would be a problem in the United States, where pesticides have been widely used, since insects can accumulate dangerous levels of pesticides in their bodies.

In summary, there are potential hazards from eating certain insects. People who normally eat insects have learned by experience and observation to avoid certain ones that may be poisonous. If we are to introduce various species of insects into our diet, we should proceed with the same cautions that we would use with any other new food or food ingredient.

IV. Insect Reproduction, Requirements, and Raw Materials Conversion

Insects are an ideal protein source from an efficiency standpoint. They can reproduce in tremendous numbers at incredible rates, many have simple requirements, and they are highly efficient food converters. For an exhaustive treatment of insect biology, an entomology text should be consulted. Some representative facts have been included to illustrate the great potential of insects as food for industrialized nations. Due to strong prejudices against the idea of seriously using insects in the human diet, relatively few species have been studied in terms of controlled rearing practices, selective breeding, and raw materials conversion. Most of the efforts to raise and selectively breed insects have been directed at insect eradication, not human consumption.

The reproduction rates of insects are staggering, as anyone with a household ant or cockroach problem can confirm. The housefly can reproduce at a rate of 550 million per year (of course, houseflies do not live that long), and some queen bees produce 1000-2000 eggs per day. The Egyptian locust lays an average of 195,000 eggs per month, and some termites (*Bellicositermes*) can lay 36,000 eggs per day (Eerde, 1980/1981). Insects have to reproduce in large numbers, due to the small percentage of offspring that survive. Most do not survive because of predators, severe environmental conditions, diseases, and lack of parental care in many species. Under controlled conditions, many more insects of desirable species could be induced to survive. Animal husbandry techniques could be utilized to develop larger, more nutritious, and healthier specimens.

The only insect raised for human food in Western countries is the honeybee. Although only the honey is normally eaten, bee pupae and larvae (bee brood) are edible and nutritious. Taylor (1975) believes that Americans are probably less negative about honeybees than other species. Since bees are social insects, they maintain their hives by themselves. Caron (1978) states that 3-4 pounds of bee brood can be harvested from a normal colony.

Besides the honeybee, many other types of insects would be easy to raise. The termite, also a social insect, is an example of a species already eaten by many people in the world. Other insects suitable for large-scale rearing are the greater wax moth, the corn earworm, and some giant silkworm moths (<u>Antheraea</u> species). An unsuitable species would be the codling moth, since it has complex needs and is inefficient at food conversion. Taylor (1975) includes a chapter on how to raise crickets, mealworms, greater wax moths, and flour beetles (which many people do inadvertently). Crickets require a very clean environment; therefore, they are potentially more appetizing as human food. They can be fed a simple diet of apples and bran (Collins, 1981). Of course, many insects would not have to be raised on the same foods that humans eat. As with domestic animals used for human food, insects could be raised on a defined diet that improves their flavor to suit human tastes. Research on how to raise wasps on a large scale for human food is being conducted in Mexico, where insects (such as the screwworm fly) are currently raised for eradication programs (Eerde, 1980/1981).

The ability of insects to convert food not only qualifies them as valuable protein sources but also indicates their potential ecological value in waste recycling. Food conversion is the ability to convert the food consumed into body weight. The most efficient food converters gain more body weight per pound of food consumed. Although some insects are more efficient food converters than others, insects generally compare well with domestic meat animals. For example, grasshoppers are considered poor converters, but they are about as efficient as cattle, which are about 10% efficient (% of food consumed that is converted to animal tissue). Chickens are the most efficient food converters (38-40% efficient), whereas sheep and lambs are only about 5% efficient. Fish and shellfish are 10-20% efficient. The silkworm has food conversion efficiencies of from 19-31%, the confused flour beetle is about 40% efficient, and the greater wax moth larva is 20-30% efficient (Taylor, 1975; Caron, 1978).

Another way of looking at food conversion is in terms of energy. Green plants are primary producers that capture solar energy to synthesize their food, which ultimately becomes our food. Modern agricultural techniques involve the expenditure of a great deal of energy for mass production of green plants for human consumption. These green plants also serve as food for livestock, since meat is an important part of the diet in Western cultures. Thus, cattle and pigs become intermediate consumers, and the energy efficiency of the plants they eat is reduced. In fact, livestock are fed the more energy efficient grains, such as corn, oats, wheat, and sorghum, which could be more efficiently consumed directly by people (Heichel, 1976). Insects would not have to be fed valuable human food, if they were raised for human consumption. Many herbivorous insects are very efficient at secondary production, or storage of energy from green plants (Gorham, 1976).

Another way of taking advantage of the energy efficiency of insects is to feed them to livestock. Animal manure and other agricultural wastes could also be recycled by raising insects on the wastes and then feeding the larvae to domestic animals. Both of these possibilities have been tested. Two pigs were fed a diet containing locust meal as a protein supplement of about 20% of the ration. After slaughter, the pork was taste-tested. All of the tasters indicated that the meat had a fishy flavor (DeFoliart, 1975). It seems unlikely that all species of insects would produce the same adverse effects on taste in the meat of livestock.

Preliminary studies have been conducted using insects for agricultural waste recycling. Various species of flies seem to be promising for this application. Koo et al. (1980) reared face fly (*Musca autumnalis* (De Geer)) larvae on dairy cattle manure. The larvae were transferred to dry sand to pupate, after the larvae voided their intestines. The pupae were collected from the sand by sifting and then fed to day-old Single Comb white Leghorn chicks. In one group dried, ground pupae replaced the soybean meal as the protein source. In another group, half the soybean meal was replaced by the pupae. A control group received the regular corn-soybean meal diet. After 4 weeks, no toxic effects were found in the chicks. A slightly decreased feed efficiency was found, because the diets containing fly pupae had fewer calories per gram. Growth rates were therefore somewhat poorer. It was concluded that face fly pupae could be utilized in recycling manure nutrients and in feed for poultry. Face fly pupae also have high levels of calcium, phosphorus, magnesium, and trace elements. Face flies are superior to houseflies for this use, because they are larger and susceptible to fewer diseases.

Similar studies using housefly pupae were reviewed by DeFoliart (1975). The meat of the chickens given fly pupae as part of their diet was of good quality with no unpleasant tastes. The fly larvae also reduced the amount of poultry manure by about half, after which the odor of the manure was improved. Manure biologically processed in this manner could also be used as fertilizer. Insects might be used directly as fertilizer, as ground up locusts have been in Argentina (Bodenheimer, 1951).

More research is needed on the various applications of insects in recycling wastes, on insects as feed for domestic animals, in identifying the most appropriate species for these applications, and in better large-scale insect raising facilities. In the next section, the nutritional value of insects will be reviewed.

V. Nutritional Properties and Composition

For many years people have realized that insects are high in protein. In fact, when someone finds an insect in his food, a typical reply is "Oh, don't worry, it's just a little extra protein!" Although the nutritional potential of insects has been recognized, very few of the million or so insect species have been analyzed scientifically for nutrient composition. The most current studies available on insect composition are reviewed below. Many of the older studies lack details on the methods used or the exact species tested. Despite these limitations, some of the older data have been included on insects for which more reliable data are unavailable.

The major constituents of insects are water, proteins, and fats, with smaller amounts of chitin, carbohydrates, minerals, and vitamins (Gamble, 1976; Meyer-Rochow, 1976). The amounts of these substances vary greatly with different species. Chitin is a substance present in the exoskeleton of insects and other arthropods. The exoskeleton of insects is called the cuticle and is often hard and shiny. Although the cuticle would seem to make insects difficult to digest, a freshly killed adult locust has only 4% (wet weight) indigestible cuticle (Taylor, 1975). Chitin is about 10% of the dry weight of an adult locust (Bodenheimer, 1951).

All of the sources used in this review were unanimous in stating that insects contain high quality protein in amounts comparable to or exceeding that of livestock, poultry, and fish.

Raw beef has about 17-19% protein, raw pork has about 14-16%, chicken has about 20-23%, and fish has about 18-20%.

There is a word of caution about the data on protein content. The crude protein calculation is based on the nitrogen content, which is multiplied by a conversion factor of 6.25. La Fage (1976) notes that the actual conversion factor of nitrogen to protein ranges from about 5 to almost 8 in different animal species, as well as among different tissues within the same animal. There may also be differences between individuals of the same species. The protein content must therefore be considered a rough estimate at best. Since this method for calculating the protein content of insects has been used by the vast majority of investigators, the limitations of the estimates should be considered when interpreting the data.

Some of the more reliable nutritional information on insects comes from currently active researchers in the field. These researchers have all been concerned about nutrition in Third World countries, as well as the entire world due to projected population increases by the year 2000. A team of scientists, led by Dr. Julieta Ramos Elorduy at the Department of Zoology of the Biological Institute at The National Autonomous University in Mexico (UNAM) is studying various aspects of insects as human food. They have cataloged about 473 edible insect species in Mexico, where insects are commonly used as food by a number of people. Mass production methods of raising insects are being considered, and a survey of Mexico City residents showed very favorable attitudes toward the use of insects as food. The research team has analyzed the protein content of many of the insects. They found that wasps have the highest protein content, 81%, based on 100 grams dry weight. Protein values for other insects included 60% in grasshoppers, 43% in honeybees, 64% in houseflies, and 30% in the maguey worm. Most insects also contain the correct amino acid composition required for human nutrition by the Food and Agriculture Organization of the United Nations (Eerde, 1980/1981; Mamley, 1976). It should be noted that both of these sources of information on the UNAM research are popular publications, not scientific journals. Many useful details have been omitted in these articles.

Another series of analyses were done recently on 24 edible species of caterpillars by Malaisse and Parent (1980) at the National University of Zaire. The caterpillars were collected in Zaire (formerly the Congo), in Central Africa. The caterpillars were prepared for chemical analysis by the same methods used before cooking by people living near Lubumbashi, Zaire. Larger caterpillars (of the Attacidae family) have their intestinal tract removed, after which they are rinsed in water. The furry caterpillars, such as Imbrasia epimethea and members of the family Thaumetopoeidae, are put on a hot iron (presumably to remove the fur). The caterpillars of the Notodondidae family are dropped in boiling water, so that the intestinal tract can be removed, and then rinsed in clear water. After the caterpillars were cooked, they were dehydrated by lyophilization, ground into powder, and stored in polyethylene bags in a dessicator until analysis.

Nutrient analyses were performed using standard methods recommended by the Association of Official Agricultural Chemists (AOAC) in 1960. The nitrogen content was measured by the Kjeldhal method, and the protein content was calculated using a 6.25 conversion factor. Lipid content was measured by extraction with petroleum ether for 8 hours in a Soxhlet apparatus. Fiber content was measured using the method of Kursher and Hanak modified by Ladd (in Winton and Winton, The Analysis of Foods, John Wiley and Sons, NY, 1947). Ash was produced by heating a 10 gram sample to 600°C. Carbohydrate content was estimated by subtracting the total amount of (protein + lipid + fiber + ash) from 100. Phosphorus and iron were determined by the official AOAC spectrophotometric methods, and calcium was determined by titration of calcium oxalate in sulfuric medium with a standard solution of potassium permanganate. Nutrient values for the 24 species of caterpillars are shown in Table III.

TABLE III

Caterpillar Nutrient Analyses

	Average	Range
*Protein	63.5 ± 9.0	45.6 - 79.6
*Lipid	15.7 ± 6.3	8.1 - 35.0
*Fiber	8.5	6.5 - 11 (7 species only)
*Ash	5.87	3.7 - 8.8
*Carbohydrate	12.07	1.0 - 29.4
**Caloric value	457 ±32	397 - 543
***Calcium	202.9	20 - 500 (21 species only)
***Phosphorus	908.6	500 - 2,300 "
***Iron	64.3	10 - 200 "

*g./100 g. dry wt.

**Calories (kcal.)/100 g. dry wt.

***mg./100 g. dry wt.

As the data above indicate, caterpillars can be a highly nutritious dietary supplement that is high in calories. Oliveira et al. (1976) at the Universidade Nova de Lisboa in Portugal have performed nutrient analyses on four insects traditionally consumed in Angola. The insects analyzed include two caterpillars, Imbrasia ertli (Rebel) and Usta terpsichore (Massen and Weymer), an adult termite (the reproductive stage or alate), *Macrotermes subhyalinus* (Rambur), and the palm weevil larva, *Rhyncophorus phoenicis* (F). The insects were prepared by frying in oil, after which they were vacuum dried, powdered, and stored at a low temperature until analysis. The analyses included fat, protein, amino acids, B vitamins (thiamine, riboflavin, and niacin), fatty acids, and minerals (phosphorus, potassium, sodium, calcium, magnesium, iron, copper, zinc, and manganese). Complete references are provided for all the analytical methods used. Brief descriptions of each analytical method are provided in the article and are summarized in Table IV.

TABLE IV

Methods for Nutrient Analyses

Nutrient	Analytical Method
fat	extraction with sulfuric ether in a Soxhlet apparatus
protein	Kjeldahl method for nitrogen times a conversion factor of 6.25
ash	produced by heating to 425°C
carbohydrate	calculated by difference
phosphorus	colorimetry
sodium and potassium	flame photometry
calcium, magnesium, iron, copper, zinc, and manganese	atomic absorption spectrophotometry
amino acids and vitamins	microbiological assays
fatty acids	gas chromatography

Although all four of the insects tested by Oliveira et al. (1976) are nutritious, the caterpillar of the moth Usta terpsichore was found to have the highest nutritional value. High levels of zinc, iron, phosphorus, calcium, thiamine, and riboflavin were present in this species. The adult termite, Macrotermes subhyalinus, has a high fat content and thus a high caloric value, as well as high levels of copper and manganese. The palm weevil larva (Rhyncophorus phoenicis) also has a high fat content and caloric value and large amounts of thiamine, riboflavin, zinc, and iron. The investigators also provided an estimate of the amounts of the daily human requirements obtained for certain nutrients by consumption of 100 grams of each insect species tested. This was shown by expressing the nutrient value as the percentage of the daily requirement for a "typical man" as recommended by the Food and Agriculture Organization of the United Nations. The results of the nutrient analyses and the percentages of daily requirements are summarized in Tables V and VI.

TABLE V
Nutrient Content Per 100 Grams Insect

Nutrient	Macrotermes subhyalinus	Imbrasia ertli	Usta terpsichore	Rhynchophorus phoenicis
Energy (kcal.)	612	375	371	562
Protein (g.)	38.42	48.66	44.10	20.34
Fat (g.)	46.10	11.08	8.60	41.73
Ash (g.)	6.56	14.36	11.77	2.39
Carbohydrate (g.)	7.98	16.88	26.29	24.79
Phosphorus (mg.)	438	546	695	314
Calcium (mg.)	40	50	355	186
Magnesium (mg.)	417	231	54	30
Sodium (mg.)	1969	2200	3031	40
Potassium (mg.)	476	1095	2958	1972
Iron (mg.)	7.5	1.9	35.5	13.1
Copper (mg.)	13.6	1.4	2.4	1.4
Zinc (mg.)	*	*	23	23.7
Manganese (mg.)	63.8	3.1	6.1	0.7
Thiamine (micrograms)	131	*	3670	3020
Riboflavin (mg.)	1.14	*	1.9	2.24
Niacin (mg.)	4.59	*	0.3	3.0
Principle Fatty Acids (% of total fat):				
Palmitic acid (%)	33	22	27.4	36
Palmitoleic acid (%)	33	22	27.4	36
Oleic acid (%)	9.5	2.0	1.7	30.0
Linoleic acid (%)	43.1	20	27.2	26.0
Total Essential Amino Acids (g/gN)	2.218	1.640	3.357	2.236

*Not determined

TABLE VI
Percentages of Daily Requirements Provided by 100 Grams Insect

Nutrient	*Macrotermes subhyalinus*	*Imbrasia ertli*	*Usta terpsichore*	*Rhyncophorus phoenicis*	Daily Requirements
Energy	21.5%	13.2%	13.0%	19.7%	2850 kcal.
Protein	38.4	26.3	76.3	18.1	37 g.
Thiamine	8.7	not given	244.7	201.3	1.5 mg.
Riboflavin	67.4	not given	112.2	131.7	1.7 mg.
Niacin	47.7	not given	26.0	38.9	20 mg.
Calcium	4.0	5.0	35.5	18.6	1 g.
Phosphorus	43.8	54.6	69.5	31.4	1 g.
Magnesium	104.2	57.8	13.5	7.5	400 mg.
Iron	41.7	10.6	197.2	72.8	18 mg.
Copper	680.0	70.0	120.0	70.0	2 mg.
Zinc	not given	not given	153.3	158.0	15 mg.

Another research group, led by Dr. Nutting in the Department of Entomology at the University of Arizona, has been studying termite composition. La Fage (1976), one of Dr. Nutting's graduate students, wrote his doctoral dissertation on the nutritional biochemistry of a local dry-wood termite, *Marginitermes hubbardi* (Banks). Some data on another termite, *Reticulitermes flavipes*, are also included for comparison. A number of detailed biochemical analyses were performed in this research, of which some of the most significant data will be presented. The reproductive form, or alate, has wings and is the stage most often consumed (after the wings are removed) by humans. Table VII summarizes the nutritional data, most of which are for the alate stage.

The Food and Agriculture Organization of the United Nations, located in Rome, Italy, cooperated with the U.S. Public Health Service to produce a series of tables on the nutritional value of foods in Africa. This large compilation contains an alphabetical listing of the nutrient composition of all kinds of food, including insects. Table VIII contains data on termites (species unspecified) prepared several ways (Wu Leung, 1968).

One of the earliest papers on the nutrient value of termites is by Tihon (1946), who was the Director of the Chemical Laboratory of East Leopoldville in the Belgian Congo (now called Zaire). Tihon collected some fried termites which were on sale in a local market. Using the coefficients of Rubner, the caloric value of 100 g. of these termites was found to be 560.52 kcal. per 100 g. Table IX shows the values of other nutrients.

The witchetty grub, eaten by certain groups of Australian aborigines, has also been analyzed. Meyer-Rochow (1976) reported the results of analyses performed in Adelaide, but no details on the methods were provided. The witchetty grub, which is a caterpillar, weighs about 1.2 g. wet and 0.777 g. dry. The dry weights of nutrients were 38 g. protein, 5.7 g. carbohydrate, 39.8 g. fat, 16.2 g. fiber, as well as some zinc, copper, iron, and vitamins A and D.

Dried face fly pupae, <u>Musca autumnalis</u> (De Geer), have been suggested as a poultry feed by Koo et al. (1980). Not only would fly pupae be useful as domestic animal feed, but also nutrients from manure could be recycled. The face fly pupae were analyzed for protein, fat, ash, energy, and biotin content using standard methods of the AOAC (Association of Official Agricultural Chemists). Amino acids were analyzed using gas liquid chromatography, and minerals were determined using atomic absorption spectrometry. The results showed that the amino acid composition was similar to that of many other animal proteins. Table X summarizes the other nutrient data.

The last insect for which nutritional data will be provided is the honeybee. Caron (1978) states that bee brood (the larvae and pupae) is high in vitamins A and D, protein, and fat. Bee brood is good to eat, but does not seem to have played a large role in the diets of many people. On the other hand, the bee product, honey, is a substance of almost universal appeal. Honey is a major source of carbohydrates and is a solution of the simple sugars, fructose and glucose. It also contains some vitamins, minerals, acids, and pollens. Bianchi (1977) states that honey is more easily digested than table sugar (sucrose), contains organic acids that improve the appetite, is a quick source of energy, and when mixed with milk, can increase calcium retention in children. Although honey is rich in carbohydrates, another bee "product," the pollen, is rich in protein. Taylor (1975) reports that about 70 pounds of pollen can be obtained from one beehive per year.

The preceding information shows that insects are a great nutritional resource. Due to space limitations, only a small portion of the insect nutrient data has been included. The emphasis has been on the most recent data, particularly from articles published after the comprehensive review by Taylor (1975).

Future research on the use of insects in the human diet should include feeding studies using various insects prepared in different ways to discover the most promising species from a nutritional standpoint as well as for acceptability. Nutritional composition data should be more systematically collected, and more data are needed on the nutritional elements present in smaller quantities, such as minerals and vitamins. As the awareness of future world food supply problems becomes more widespread, it is hoped that more attention will be given to the dietary role of insects.

TABLE VII

Termite Nutrient Data

	M. hubbardi (alate)	R. flavipes (mixed stages)
Energy value[a] (kcal./g. dry wt.)	6.41	not determined
Nitrogen (% of dry wt.)	8.65	not determined
Crude protein[b] (g.)	54.06	unknown
Lipids[c] (% of dry wt.)	46.43	12.37
Ash[d] (% of dry wt.)	4.29	-

[a] Mean caloric content determined by micro-bomb calorimetry.
[b] Estimated by multiplying the nitrogen content (8.65) by a conversion factor of 6.25.
[c] Extracted by ethyl ether in a Goldfisch extractor.
[d] Ash from combustion at 55°C for 18 hours.

TABLE VII

Termite Nutrient Data Continued

Amino acids: (% of total amino acids)	Sealed Hydrolysis Tube	Open Hydrolysis Tube	Open Hydrolysis Tube
Lysine	6.1	5.3	5.6
Histidine	2.9	2.4	2.3
Arginine	5.9	4.2	4.1
Aspartic acid	8.2	8.6	8.3
Threonine	3.9	4.9	5.2
Serine	3.4	5.2	5.1
Glutamic acid	12.6	11.7	11.3
Proline	6.6	7.4	6.7
Glycine	12.0	10.8	10.4
Alanine	8.7	11.9	11.9
Cystine	0.0	0.0	0.6
Valine	6.4	7.1	7.4
Methionine	1.6	1.8	1.7
Isoleucine	4.7	4.6	4.8
Leucine	7.6	7.6	7.6
Tyrosine	5.7	4.0	4.4
Phenylalanine	3.8	3.3	3.1
Total amino acids (% of sample dry wt.)	not given	40.17	51.60
Essential amino acids (% of total essential amino acids)	not given	42.76	53.76

TABLE VIII
Nutrient Levels of African Termites

	Raw	Dried	Fried	Smoked
Energy (kcal/100g. edible)	356.0	656.0	542.0	579.0
Fat (g./100g. edible)	28.0	54.3	42.6	44.4
Protein (g./100g. edible)	20.4	35.7	31.8	36.5
Fiber (g./100g. edible)	2.7	*	5.2	3.4
Ash (g./100g. edible)	2.9	4.8	5.1	5.4
Total Carbohydrate (g./100g. edible; includes fiber)	4.2	3.5	5.8	5.9
Thiamine (mg./100g. edible)	*	.03	.12	.10
Niacin (mg./100g. edible)	*	5.8	8.3	1.8
Riboflavin (mg./100g. edible)	*	5.97	3.23	.06
Ascorbic acid (mg./10g. edible)	*	trace	trace	0
Calcium (mg./100g. edible)	*	142.0	80.0	91.0
Phosphorus (mg./100g. edible)	*	780.0	520.0	65.0
Iron (mg./100g. edible)	*	52.0	17.4	21.0

*No data available

TABLE IX

Nutrient Data for Termites of the Congo

Fat (in petroleum ether)	44.40%
Nitrogen	5.76%
Total Nitrogenous Matter (6.25; Protein)	36.00%
Chitin	5.09%
Calcium (as CaO)	1.4%
Magnesium (as MgO)	0.32%
Potassium (as K_2O)	7.84%
Manganese	traces
Iron & aluminum oxides	11.77%
Ash	6.42%

TABLE X

Nutrients in Dried Face Fly Pupae

Energy	4.3 kcal./g.	Sodium	1.8 mg./g.
Protein	51.69%	Potassium	5.5 mg./g.
Fat	11.35%	Zinc	0.27 mg./g.
Ash	28.94%	Magnesium	11.5 mg./g.
Biotin	0.57ug./g.	Iron	0.25 mg./g.
Calcium	24.8 mg./g.	Copper	0.015 mg./g.
Phosphorus	27.4 mg./g.	Manganese	0.66 mg./g.

VI. Preparation of Insects as Human Food

Insects are best when cooked live, as is the case with most shellfish. After death, they must be cooked immediately because bad tastes form quickly (Taylor, 1975). Insects are most commonly eaten raw (live), roasted, or fried. Insects can also be boiled, curried, added to stews or soups and other dishes, or ground up and then added to flour for making various pastries. Before cooking and/or eating, the heads, legs, and wings of many species are removed, because these tend to be sharp and indigestible. The intestinal tract of some insects (such as palmworms) must be removed to avoid bad-tasting plant material that insects may eat.

Since insects are eaten all over the world, only a few recipes will be included in this review. Most insect recipes are quite simple, including few spices other than salt and pepper. In Morocco, locusts (migratory grasshoppers) are prepared by removing their heads, legs, and wings, sprinkling them with salt, pepper, and parsley, and then frying them in butter with some vinegar. Locusts are also roasted, boiled, curried, or powdered (locust meal) and baked into cakes (Holt, 1885).

Giant water bugs, which are eaten in both Mexico and Asia, were prepared by the Siamese as follows: steamed and then soaked in shrimp sauce; then pounded up and added to curries and sauces. One of these sauces consisted of shrimp, garlic, pepper, and lime juice (Bristowe, 1953). The giant water bug is said to have an odor something like flowers. The Cantonese usually prepare this bug by dropping it in boiling water with salt; sometimes the bugs are deep fat fried with spices (Hoffman, 1947).

Silkworm pupae are also commonly eaten in China by the women who work in the silk industry. The silk is extracted from the cocoons by dropping the pupae into hot water, which cooks the silkworms, after which they are eaten by the factory workers. Other cooking methods for silkworms are roasting, boiling, or sauteeing (Taylor, 1975).

Besides the silkworm, caterpillars of both moths and butterflies are also eaten in Angola, Zaire, and other African countries. They may be cooked in water, roasted, or dried in the sun, with salt added before being eaten. Dropping caterpillars in boiling water enables the intestinal contents to be removed, which improves the taste of many species. Further cooking such as roasting or frying may then be done if desired (Oliveira et al., 1976; Malaisse and Parent, 1980).

The French, whose tastes are normally quite adventuresome anyway, became enthusiastic consumers of palmworms (*Rhynchophorus palmarum* L.) when they colonized the West Indies in the 18th Century. The preferred cooking method was to roast the grubs on a spit over an open fire, during which they were sprinkled with a mixture of bread crumbs, salt, pepper, and nutmeg. When done, they were served with orange juice (Bodenheimer, 1951). In Angola, another species of palmworm (*Rhynchophorus phoenicis* F.) that infests the oil palm is fried whole in oil (Oliveira et al., 1976).

Contemporary insect recipes can be obtained from Mexico, where many insect varieties are eaten. Some recipes involve adding insects to traditional meat dishes. For example, mosquitoes are added to tamales and ant eggs are mixed inside tacos. Honey ants are eaten (probably raw) for dessert. Since certain gourmet restaurants in Mexico serve insect dishes, some unusual insect recipes might be obtained from a survey of menus in Mexico City. A number of canned insects (maguey worms, bees, ants, and fried grasshoppers) are exported from Mexico as gourmet items (Eerde, 1980/1981).

Caron (1978), who teaches an apiculture (beekeeping) course at the University of Maryland, serves bee brood to his students. Bee brood consists of honeybee larvae and pupae. His students tried a number of recipes, including deep fat fried, pan fried, brine pickled, smoked, baked, and brandied bees. Deep fat frying was the tastiest method, and the flavor was described as like walnuts, Rice Crispies, or pork crackling.

Termites, like locusts, are eaten all over the world. Termites are usually either roasted or fried; they can also be sun-dried and stored. The oil from termites can be extracted and used in cooking. Taylor (1975) borrowed a recipe for dried termites (or other edible insects) from the Bantus of South Africa. After removing the wings, the insects are placed in an oven on a cookie sheet at a low temperature. The dried insects are then fried in vegetable oil until almost crispy. They can be eaten immediately with salt or stored for months before eating.

Taylor (1975) also has a recipe for preparing dragonflies. The wings are removed, after which the insects are fried with onions or spices and vegetables in oil.

An insect that is easily obtained and has potential for enhancing many foods is the mealworm, the larval stage of a common grain beetle (Tenebrio molitor). Mealworms are sold in pet shops as food for tropical fish, reptiles, and birds. A recipe for chocolate chip mealworm cookies was devised by Kay Weisberg, Director of the Insect Zoo of the Smithsonian's Museum of Natural History in Washington, D.C. The cookies were served at a lecture at the museum on "Cooking with Insects" in August of 1981. The presence of the mealworms was not detectable--the cookies looked and tasted like normal chocolate chip cookies. Due to a shortage of mealworms, Weisberg used 1/2 cup ground up mealworms per 1 cup flour in a standard chocolate chip cookie recipe. A 1:1 ratio of mealworms to flour would have imparted a "nutty" taste to the cookies, according to Weisberg (1981). The live mealworms were first prepared by placing them in a freezer for 15 minutes or so to anesthetize and immobilize them. They were then roasted on a cookie sheet in an oven, after which they were ground up and mixed with the flour. Taylor (1975) suggests soaking beetle larvae in coconut milk and then roasting them. This recipe is probably more effective with species larger than the mealworm.

Taylor (1975) has a number of other insect recipe ideas, of which only a few have been mentioned. This entomologist is knowledgeable about insect recipes, because he eats insects himself and has served them to his college students and colleagues in California. His advice on trying canned insects is that none are as good as the freshly cooked ones. The only canned insect he recommends is the agave (maguey) worm from Mexico, which goes well with cocktails.

It seems that entomologists have long been intrigued with the food potential of the animals they study. In fact, Taylor (1975) acknowledges another professor of entomology as the person who first introduced him to eating insects. Dr. Margaret Collins, a zoologist at Howard University in Washington, D.C., and an enthusiastic supporter of insects as human food, also attributes her first experience eating insects to an entomologist (Collins, 1981).

Since the reader may not have had an opportunity to eat insects, especially those that are freshly prepared, Table XI summarizes the flavors of some of the common species.

TABLE XI

Reported Flavors of Insects

Insect	Stage	Preparation Method	Flavor	Ref. #
Grasshoppers (locusts)	adult	fried in their own oil	nutty	37
Termites	adult	live	pineapples	37
"	"	roasted with salt	vegetable-like	4
"	"	unspecified	delicate flavor	6
"	"	roasted	lobster, snail, mushroom	37
Dragonflies	nymph	boiled	crayfish	37
Witchetty grubs (caterpillars)	larva	roasted	nutty, oysters, roast pork, or sweet scrambled eggs	3, 37
Maguey worm (caterpillar of the skipper butterfly)	larva	fried and then canned	nutty	37
Greater wax moth	pupa	live	uncooked fresh shelled peas	37
Bugong moth	adult	heated on a fire to singe off wings and scales	nutty	37
Butterflies	adult	unspecified	sweet	37
Leaf-cutter ants	adult	toasted	bacon	37
Bee brood	larva; pupa	deep fat fried	walnuts, Rice Crispies, or pork crackling	6
Flour beetle (Tribolium)	larva	fried in vegetable oil and salted	sunflower seeds, chicken, or pork crackling	37
Dynastid beetle	larva	roasted (after being soaked in coconut milk)	mixture of vegetables (with parsnips)	4

VII. Summary

All of us regularly eat whole insects or insect parts, due to unavoidable contamination of foods, such as vegetables, fruits, grains, and spices. We also eat animals who eat insects, including fish, birds, and some livestock. Most members of industrialized societies find these facts rather distasteful and would prefer not to be reminded of them. The only significant dietary usage of insects by European cultures has been in folk medicine.

With the exception of Europe and North America, insects are consumed nearly everywhere. Due to the pervasive influence of Western culture, entomophagy is not quite as common now as it was a few years ago. Yet insects are still eaten in many countries of Africa, in Southeast Asia, by some Australian aborigines, and by Indians in North, Central, and South America. Insects have been important protein sources for many of these peoples. The insect product, honey, has also been an important source of carbohydrates to many of the more primitive societies. The most common species eaten in the world is the grasshopper; the termite is the second most common. Other insects that are often mentioned as human food are beetle larvae (such as palmworms), caterpillars, body lice, bees, ants, dragonflies, and giant water bugs.

There seem to be few hazards associated with eating insects. Those that have been reported include toxic compounds normally occurring in the insect or from poisonous plants in the insect's diet, allergy, parasites carried by the insects, pesticide contamination, nutritional degradation of other foods due to insect infestation, mechanical injury from sharp insect appendages, and intestinal impaction as a result of excess consumption of locusts. These potential hazards must be considered before introducing a new insect species into the human diet.

Insects as an animal group have many qualities that make them an ideal supplement to the human diet for space travel and on Earth. Most species are prolific, hardy, easy to prepare, and could be easy to raise. There are over one million insect species from which to choose, and no other class of animals has so many different forms. Certain species of insects could be utilized in the recycling of wastes, such as manure and plant residues. After feeding on agricultural wastes, insects could be used as food for domestic animals at a lower cost than regular feed. This application has been investigated with encouraging results using face fly larvae (Koo et al., 1980).

Herbivorous insects are efficient at converting the food they eat to body weight. Even one of the least efficient, the grasshopper, is about on par with cattle, which are 10% efficient (Taylor, 1975). The difference is that cattle are fed the more efficient grains, which could be used as human food directly, whereas insects do not have to be raised on valuable human foods. Therefore, if insects were raised for human consumption, a great deal of energy and costs might be saved.

Insects are especially high in protein, fat, and calories. Smaller amounts of vitamins (particularly B vitamins) and minerals are also present. The nutrient composition varies considerably from one species to another. Although, most of what we know about insects is from human experience rather than scientific study, there are scientists in the United States, Africa, and Mexico who are investigating the nutritional value of various insects for humans. These researchers have confirmed that insects are an excellent source of high quality protein.

People are less averse to the idea of actually eating insects in areas, such as Mexico and Africa, where insects have always been eaten by certain groups. Creative marketing schemes would be required in order to introduce insects into the diet of people unaccustomed to eating insects. Because current agricultural practices are not meeting the needs of all people in developing countries, insects may be part of the solution. Many scientists are predicting that there will be worldwide food shortages in the next century, unless alternative food sources are utilized. Today, much of the world's population is nutritionally deprived. Insects are a food source that is readily available, and prejudice seems to be the main deterrent to using insects as food. Current researchers recognize this problem: "While the acceptance of these foods may be limited, possibilities exist for their exploitation and use in other (perhaps more exotic and acceptable) food preparations" (Oliveira et al., 1976, p. 94).

Such alternative food preparations have already been attempted. Ground up insects such as beetle larvae and locusts have been used to produce pastries by people in South America, Africa, and other countries. In these forms, the insects may be undetected and therefore more acceptable. The use of whole insects is only one of many options. Another option for the future is the development of an insect protein concentrate, similar to the previously developed fish protein concentrate (Caron, 1978; Taylor, 1975), to be used in improving the nutritional value of familiar foods.

Their small size, food conversion efficiencies, and waste recycling abilities make insects especially interesting possibilities for use as food aboard spaceships. Research on insects as dietary supplements in space will have potential benefits to humans all over the world. Insects do not have to be regarded as a last resort food for the starving masses. Countless numbers of people can testify to the fact that many insects not only have a pleasant odor during cooking but also a delicious flavor!

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